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PROFILES IN SCIENCE

George P. Woollard

George P. Woollard is best known for his work in standardizing gravity on a global basis and for the number of students he has taught who have made a name for themselves. He is also noted for his role in revitalizing the study of the earth's crust and in establishing an integrated program of study for the polar regions during the IGY.

Dr. Woollard is Director of the Hawaii Institute of Geophysics, University of Hawaii. During the last 10 years, he has had a vital part in making the Institute a center for scientific investigations ranging from astronomy to marine geology and geophysics. During and after World War II, while he was at Woods Hole, Woollard was instrumental in advancing the understanding of underwater sound transmission. His comprehensive manual on factors governing sound ranges was the first such manual, and the basis for the Navy's subsequent tactical manuals. Similarly, his report on a comparison of echo ranges at 11 and 25 kHz had much to do with changes made in active and passive sound ranging.

Mathematical Models for Menus

Joseph L. Balintfy
University of Massachusetts

Introduction

Volume feeding decisions are concerned in general with the problem of feeding a given population by converting raw food, with the aid of labor and some facilities, into edible food products–called menu items–and delivering meals which meet the preferences of the population, are nutritionally adequate, and can be produced within the given budget.

In recent years, food technology and the food service industry have made great progress, especially in the direction of modernizing the conversion process and thus simplifying the logistic, food production and meal delivery part of the decision problems involved. The investigation underway at the University of Massachusetts concentrates on the possibility of modernizing and optimizing meal delivery systems from the point of view of the customers. By customers we mean here "captive" populations such as the crew of a ship, troops assigned to a mess hall, patients of hospitals or nursing homes, students at universities, or even inmates in penal institutions. The Navy in both ships and hospitals is a participant in the food service industry. The techniques described in this article, suitably modified for the Navy's special requirements, will be of benefit.

The argument is advanced that in all of these cases the menu from which the meals are selected defines almost exclusively the attainable preferences, nutritional adequacy, and cost of the meal service system for the given population. Furthermore, if the menu is non-selective, the food management's control over these attributes of the meals is complete. Consequently, the question of optimizing meal delivery from the customer's point of view can be reduced to the simpler decision problem of how to plan menus which are the best in some sense for a given population while meeting prescribed dietary, budget and food production constraints.

It has been known for a long time that food cost and nutritional attributes of meals and menus are quantitative data which easily yield to mathematical formulation. For this reason earlier attempts

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*Dr. Balintfy is Professor at the School of Business Administration, University of Massachusetts. His field of interest is applications of mathematical programming.

of mathematical modeling were cast in the form of linear programming [2, 3] and integer programming formulations [1, 9]. In terms of the latter approach, an optimum menu was defined as the least cost combination of menu items which satisfies given nutritional, structural and "separation" constraints for a sequence of days. The separation constraints were to assure the acceptability and variety of the menus and thus served as implicit parametric expressions of preferences. This was necessary mainly because at that time clear understanding as to how to measure food preferences and how to use the information in menu planning was not available. Nevertheless, the "least cost," or more correctly the "best buy," principle of menu planning has been successfully implemented with computer assistance in a number of institutions where food cost saving, subject to maintaining given nutritional and acceptance levels, was the operational objective [7, 8].

The current investigation is concerned with a more general and hopefully appropriate formulation of defining optimum menus. It will be shown that there are ways to determine food preferences of an individual or a population quantitatively, and hence it is possible to define with mathematical precision what the conditions are that a preference optimized menu should satisfy, and how to plan one.

This paper is organized into three parts. First the modeling principles of food preference measurement are outlined. The point is made that understanding of the theoretical foundations is necessary before surveys can be conducted with the hope of utilizing the responses in a systematic way for food service decisions. The techniques presented make it possible to survey food preferences routinely for large populations and integrate this information quantitatively into the meal delivery system.

The second part introduces the concepts and the mechanism to meet population preferences optimally by menu plans. It is shown in the framework of the constrained optimization techniques of mathematical programming that optimality conditions can be defined for menu plans with respect to preferences, cost, nutrition, and any other set of parameters. This approach to menu planning provides an automatic conversion formula from population preference measures to optimum menus while maintaining food production control on any desired level.

Finally, a possible interface between the current state of theory and the data basis available in volume feeding systems is defined in the form of computerized food management information processing systems. Food experts and model builders have a common interest in this development, though for different reasons. The information

processing capacity of such systems can be considerably enhanced by further use of mathematical models and control mechanisms. The use of electronic computers is forseen as a central tool aiding and optimizing volume feeding systems for the benefit of all.

Modeling Food Preferences Over Time

We all know from personal experience that the pleasure derived from eating most foods is somewhat related to the time when the given food was last consumed, and possibly antecedently to earlier consumptions in the past. This phenomenon can be attributed to the "frequency of servings" or "monotony" in the menus we face. Two earlier studies [6, 11] established that food preference and frequency surveys can measure and verify this phenomenon.

If we look at consumption over some fixed period of time, N, with fixed intervals of time between meals, t, relations between food preference and frequency of service can be obtained. The service frequency is $X = N/t$. We have determined that the preference frequency function is given by

$$g(x) = \left(a - \frac{be^{-c/x}}{1 - e^{-r}}\right)x$$

where a, b, c, and r are constants that determine the shape of this function for each individual and for each food item.

Figure 1 displays the form of the preference-frequency function based on survey data obtained from Astronaut Kerwin estimating his preference-time functions for the menu items of the Skylab mission. The figure refers to preferences as utility measures, which is correct since the data were collected on a centered ratio scale. The scale of x is labelled as quantity in terms of servings per 28 days, which is the dimension of frequency in the given case.

Figure 1 shows that the food preference is increasing with the increase of the frequency of serving to a maximum. Then it begins to decline. This preference maximum—called the bliss point by some economists—is reached at different levels and at different frequencies for the different foods. The figure shows how one particular individual feels about two foods, but the generalization is imminent. Every individual for all the foods he knows has internal preference-frequency functions which can be elicited, analytically represented, identified, stored and even clustered by the appropriate survey and computer techniques.

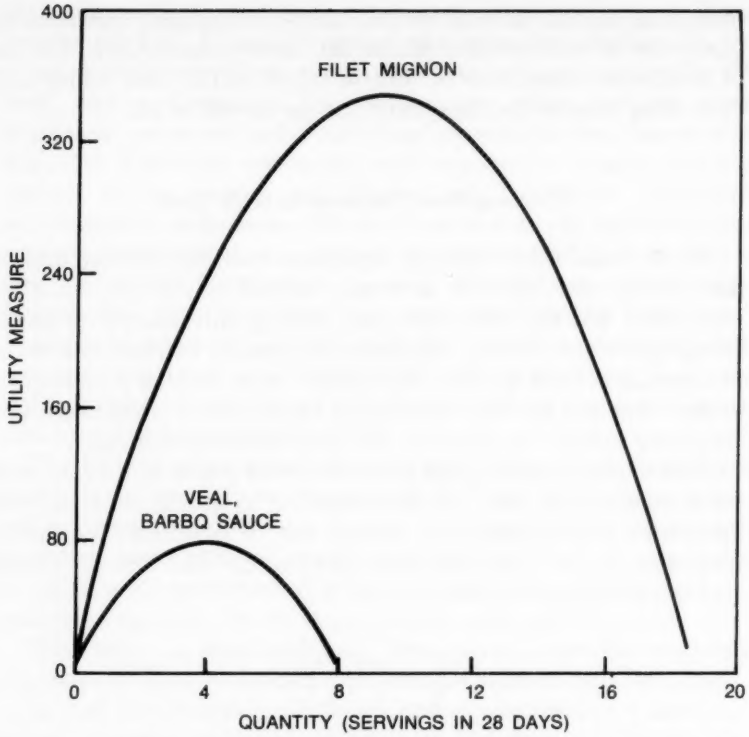

Figure 1–The preference-frequency functions of astronaut Dr. Joseph Kerwin for two selected items of the Skylab menu.

The preference surveying technique explored in reference [5] indicates the ease with which the parameters a, b, c, r can be obtained. One question should determine the preferred frequency or bliss point for the food item, while a second question should determine the level of preference for the individual when the food is served at this frequency. Finally, the level of preference for the food if it had not been served for a long time, say a year, must be determined. These pieces of information when combined with the analytic properties of the preference-frequency function are sufficient to determine the function exactly. It can be said that the introduction of mathematical modeling to the investigation of food preference measurements resulted in a mechanism which not only led us to understand the nature of the phenomenon better, but also provides us with practical computational means to store and utilize the information in quantitatively meaningful form.

It is envisioned that food preference surveys and computerized data banks containing the coefficients of preference- frequency functions of populations will be routinely used in the future by organizations concerned about the exact status or change of the food preference profile of populations.

It is further envisioned that as the accuracy of preference measurements increases, quantitative levels of population preferences can not only be observed, but also maintained over time by the techniques described in the next section. This prospect may result in a method of minimizing the impact of food price changes on food production cost, as is shown in reference [4].

Maximizing Food Preferences by Mathematical Programming

The previous section introduced the methodology of obtaining quantitative descriptions of preferences for foods in such a form that the frequency of servings is part of the definition. Moreover, by determining the bliss points the unconstrained optimum of the serving frequencies is also defined. This is already a significant step toward optimizing menu planning which is known to be a decision problem concerned with the questions of which menu item, and how many times it should occur on the menu in a given time horizon, called the menu cycle.

Before discussing menu planning for a population, we shall consider planning for one individual who has enumerated his frequency-preference views for all foods likely to be on the menu. The general conclusion is that for any such individual, given his preference estimates and a predetermined cycle length, there exists a uniquely definable serving frequency distribution at which his total preference will be maximized. A one-to-one correspondence is thus established between the notion of stated preferences and corresponding optimal menu plans. One typical property of this optimum is that the items may not necessarily be served as frequently as desired on the questionnaires. In the author's experience, the sum of bliss point frequencies always tends to exceed the cycle length contemplated by food management, and hence the items will have to be scheduled less frequently than desired. The frequency reductions for a set of items is, however, not proportional, as Figure 2 shows, but follows the rule of equalizing incremental preferences. This shows again that without the contribution of mathematical models correct interpretation of food frequency questionnaires is not possible. The difference is the "price" of the

Dinner Entrees	Bliss Points	Optimum Frequencies		
		Cycle-Constrained	Within ± 20% of Nutrient Levels	Within ± 10% of Nutrient Levels
Prime Ribs of Beef	9	8	7	3
Filet Mignon	9	8	6	1
Lobster Newburg	4	3	2	0
Chicken W/Gravy	2	1	2	4
Turkey W/Gravy	2	1	1	1
Pork Loin W/Dr. Gr.	2	2	2	2
Veal W/BBQ Sauce	4	3	3	5
Chicken and Rice	4	1	3	7
Pork W/Sc. Pot.	2	1	2	5
Totals	38	28	28	28

Figure 2–Comparative display of the optimum serving frequencies for 28 days as derived from survey responses of astronaut Kerwin and applied to a mathematical programming model with tightening constraints.

cycle length in lost preferences called the "shadow price" in economic literature. Such information may inspire food service experts in the future to rethink their policy concerning short menu cycles.

We can now go one step further and add several constraints to the problem beyond the constraint that specifies cycle length. We wish to maximize the total preference of a person to a menu plan subject to a set of constraints that define the course structure of the meals, a set of dietary constraints which are defined to maintain or restore health, and a constraint specifying the desired cycle length. A minimum set of extensions leads to the following nonlinear programming model of menu planning:

$$\text{Maximize} \quad \sum_{k=1}^{K} w_k \sum_{j=n_{k-1}+1}^{n_k} g(x_j)$$

$$\text{Subject to (i)} \quad \sum_{j=n_{k-1}+1}^{n_k} x_j = N, \quad k=1, 2, \cdots, K$$

$$\text{(ii)} \quad \sum_{k=1}^{K} \sum_{n_{k-1}+1}^{n_k} a_{ij} x_j = d_i, \quad i = 1,2,\cdots, M$$

$$\text{(iii)} \quad x_j \geqslant 0$$

where:

K is the number of the courses per day of the menu

w_k is the relative weight of the preferences in course k, $\sum_{k=1}^{K} w_k = 1$

a_{ij} is the amount of nutrient i in one serving of menu item j.

d_i is the nutritional allowance of the diet for time period N. for each nutrient i.

In short, the model shown above is a statement to maximize the total preference of a person from a menu plan subject to (i) a set of constraints which define the course structure of the meals, and (ii) a set of dietary constraints which are defined to maintain (or restore) health. This model is therefore the most concise formula to keep someone happy as well as healthy with foods. The routine mechanism to achieve this goal is provided by nonlinear programming techniques. The new constraints (i) and (ii) imply, however, additional compromises relative to the earlier optimal preferences due to the limitations attached by the nutritional specifications. Unfortunately, the picture here becomes too complex to discuss conceptually as was possible before. Instead the issues will be outlined and illustrated partially in Figure 2 through an application to the Skylab menu problem.

Motivation for this model has originated in the problem NASA scientists faced in deciding the menu for the astronauts. 72 specially processed menu items partitioned into 17 courses formed the basis of the menu plan. There were at least 6 nutrients to consider, including four minerals which were crucial to maintain a certain level for the Skylab experiments. The nutrient composition of the menu items were known, and the data along with the astronauts' food preference questionnaires were made available for the study. The problem stated in the model thus was completely defined and subsequently solved by standard nonlinear programming techniques [10]. The complete solution has been described elsewhere, so Figure 2 shows only the optimum frequencies of the dinner entree class subject to two experimental nutritional conditions created for comparison. First, the nutrient levels to be maintained were allowed to vary within ±20% of the specifications. Only two of the six nutrients were binding in this case, yet the effect on the optimum entree frequencies is considerable. We know from the previous discussion that such change incurs preference loss–about an additional 7% in this case. Allowing only ±10% range for the nutrients further deflects the optimum

frequencies to the extent of occasional complete reversal in relative frequencies and even more depression in preference. In this case obviously a very high price is paid for achieving nutritional control through food intake. Fortunately this is not a necessary policy, since nutrient supplements can be added to the items or to the diet–as was done with the astronauts–and thus the conflict with food preferences can be effectively resolved. This process may have far reaching ramifications for the current teaching of certain dietary schools.

The stage is now set to discuss the generalizaton of the above simplified model to the more realistic conditions of volume feeding operations. This requires modeling extensions in at least two directions. One is the extension of the concept of individual food preference functions to the preference function of a population. This is not an easy task, since food preferences, and hence functions, may differ from individual to individual with respect to all the menu items under consideration and thus may lead to a large number of different menus which cannot all be served. Consequently, questions of the correct sampling and clustering techniques as well as selective menu planning procedures–in this order–must be answered. Work is currently under way in this direction.

The other necessary extension of the model involves the addition of several sets of food production oriented constraints. One of them is obviously the budget constraint which was conspicuously missing from the astronauts' diet, but is a very real one in almost any other menu planning decision. Other constraints may represent conditions on ingredient availability, proportionality relations among foods or menu items, and production or serving capacity, as well as other possible logistic constraints.

The extension of the technique of preference maximized menu planning to larger and more realistic models of mathematical programming is delayed presently in both the above discussed directions only by the lack of reliable data.

The Mathematics of Food Management Information Processing

Although the attentive reader may have obtained a pretty good idea by now as to how menus *should* be planned to meet preferences, nutritional and budgetary allowances, etc., the fact of life is that the menus currently used by even the best and largest institutions are not yet planned on this basis. There seem to be no explicitly stated objectives, constraints, measures or rules in the traditional process of

menu planning, and the information processing capacity of the human mind obviates the utility of accurate data, even if it were available. Despite this, or because of this situation, most food managers are very proud of their menu plan—whether it maximizes preferences or not—and tend to resist the idea of changing it. The proposition of applying mathematics or computers to menu planning is usually turned into a counter proposition suggesting a possible role for the computer as an information processing tool. According to this perception the main difficulties in volume feeding are related to operational, and not decision, problems and therefore the computer should assist managers with operational information. The problem is presented in the following context. Given a (usually selective) menu plan, scheduled and proven, and given a population to feed: how much food should be purchased, stored and prepared for any meal, how much will a meal cost if the food prices change, how nutritious will it be, and how can a computer answer all of these questions? It turns out that this statement of the problem is also valid, and the complexity involved is not at all trivial. In fact, this problem area is now recognized as the overlapping set of interests for food managers and model builders as well. Computerization for food management information processing does serve the managers interests in their own terms, but at the same time it contributes to the accuracy and accessability of the data base on which models of the future can be built.

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"Rust" in Lunar Dust

Scientists at the Naval Research Laboratory (NRL) studying lunar soil samples returned by Apollo astronauts, say lunar soils contain magnetite, an oxide of iron that is related to rust, but is black instead of orange and has much stronger magnetic properties.

The occurrence of either rust or magnetite in lunar samples would imply that some oxidation has occurred either on the moon or after the samples were returned to earth.

Because of the apparent absence of significant amounts of oxidizing agents at the lunar surface, such as air or water, many lunar scientists have discounted previous observations of "rusty moon rocks" as accidents which happened to the samples after being exposed to a humid atmosphere on earth.

NRL investigators say, however, if magnetite exists in the lunar soils, this "accident" explanation is not applicable, since magnetite requires high temperatures to form.

Other scientists have noted that small quantities of water form at the lunar surface when hydrogen, arriving from the sun via the "solarwind," reacts chemically with some of the oxygen which is normally present in the exposed moon rocks and soil.

NRL scientists believe that not all of this water escapes into space as previously suggested. Instead, they say, some of it has time to react with the soils during high temperature meteorite collisions, thus forming some magnetite. These magnetites may be responsible for some of the magnetism of lunar rocks, and, therefore, may hold the key to understanding the moon's magnetic past.

Laboratory experiments indicate that some of the dark colors of the moon, as seen from earth, may actually result from the presence of very tiny particles of magnetite in the older lunar soils.

The NRL theory may resolve the long standing riddle of why the oldest lunar soils are always darker than the moon rocks from which they were produced by the crushing action of meteorite collisions.

Optimization Procedures for Drag Reduction

R. E. Goodson
Purdue University

Introduction

The field of *optimization* has progressed so that increasingly complex problems may be attacked. Consequently, many of the advances in optimization theory are inspired by the richness of the problems being attacked. In the research project described below a lengthy, numerical computation of drag for submerged vehicles has been coupled with several optimization techniques to produce a design procedure for low drag body shapes. The designs exploit laminar flow, theoretically delaying the onset of turbulence for most of the body length. The optimization programs developed have independent subroutines for drag, body characterization, and optimization strategy. Thus, as better drag models, more general body characterization, or different optimization strategies become available, they may be independently tried.

An important goal for underwater vehicles is the minimization of the energy required to perform a specified task. The resulting smaller power plants would provide benefits such as increased range, larger payloads, or decreased volumes for submarines, underwater tankers, or other submerged vehicles. There are several techniques which have been suggested for reducing power requirements of such vehicles. They are usually concerned with some combination of efficient power transfer and decreasing the vehicle drag through the water, i.e. decreasing the force which opposes the motion of the body through the fluid. Propellers capable of more efficient power transfer have been designed and tested. Boundary layer control by polymer injection has shown some success in drag reduction. Also, a suction slot in the boundary layer with a stern jet has been proposed as a combination drag reduction and efficient power transfer mechanism. Each of the techniques above can be experimentally evaluated on an existing hull shape. Improvement can be quantified by running a test before and after the proposed modification.

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*Dr. Goodson is Professor of Mechanical Engineering at Purdue University. He was recently appointed Chief Scientist, Department of Transportation.

Another way to reduce power requirements for a given vehicle task and volume is to design the hull shape for minimum drag. This concept is intriguing because it requires a design program which attacks both experimental and analytical difficulties of large magnitude. Some experiments have been performed which have measured drag of bodies which were specifically designed for low drag [1], [2]. These results have been encouraging but have not forestalled the quest for the minimum drag shape. To find a minimum drag vehicle shape where the main computation of drag is by experiment on a vehicle itself requires a sequence of shapes each based on the totality of the preceeding shapes and their measured drag. This would be an expensive and time consuming task and there is no assurance at the outset that the minimum drag shape will be attained.

Analytically, the main problem in designing a minimum drag hull is the computation of the drag for a given shape. Models for the boundary layer growth, the pressure distribution, some statement on laminar stability, separation criteria, wake phenomena, and varying volumes, vehicle speed, and other constraints must all be incorporated into a set of mathematical statements. These statements must be combined to yield a solvable set of equations for the body drag. Once drag can be successfully computed some way must then be found to deduce that shape which would have drag less than any other shape having the same constraints on volume and Reynolds number (a nondimensional parameter relating the length and velocity of the body and the viscosity of the fluid).

At the Automatic Control Center of the School of Mechanical Engineering, Purdue University, optimization of complex processes has been of interest for several years. The Office of Naval Research has sponsored work in this area at the Center and a variety of problems have been attacked. Thus, when the problem of designing a low power underwater body was suggested by a colleague, Fabio Goldschmied, at the Westinghouse Research Laboratory in West Lafayette, it quickly became apparent that such a problem was a prime candidate for the application of optimization techniques. After some discussion it was decided specifically to attack the hull shaping problem for minimization of drag.

As noted above, this problem, formulated analytically, presented formidable problems. It was ideal, however, for research in optimization because the manipulable mathematical model would surely consist of a set of mathematical statements coded to be solved by computer, i.e. a deck of IBM cards (2 boxes as it turned out). The constraint set would be derived from the physics of the fluid

mechanics problem and might or might not yield "pleasant" behavior of the drag as a function of body shape. Also, it seemed that such research could produce useful results. The research was planned jointly with Westinghouse pursuing the drag computation and the Automatic Control Center supplying the optimization and computational knowledge and interest. A Ph.D thesis [13] and an ONR technical report [4] have resulted thus far from the research.

No analytical work on this problem had appeared in the literature. In addition, it was obvious that the computation of drag for even a simple case was a major problem. Therefore, the work was restricted to axisymmetric bodies with steady motion along the direction of the centerline, that is at zero angle of incidence. The flow field was assumed to be non-separating, and the effects of various wake phenomena were neglected by assuming a sharp-pointed aft body or a constant diameter tailboom.

The optimization problem was divided into three independent tasks. The first task was the computation of drag. The second was the choice of an optimization scheme which would function efficiently for the type of problem formulated. The third task was the characterization of a general body shape and the constraints which must be applied on the continuity and smoothness of the shape. The drag computation would rely on the best hydrodynamic models available. The body characterization and choice of optimization scheme would depend on properties of the drag model and the type of constraints.

As an interesting and possibly helpful exercise, the performance and body shape of natural, powerful swimmers was investigated. The dolphin, porpoise, and other swimmers have received attention as efficient swimmers [5], [6], [7], [8]. After some success in finding data on natural swimmers and comparing it with known man-made low-drag bodies, it was concluded that the shape of natural swimmers has not been optimized for minimum drag but for some other more complex criterion since their shape does not produce drag much lower than present turbulent boundary layer vehicles with drag coefficients in the medium range. This conslusion is based on meager data, at best, but the estimated drag coefficients do not indicate a low drag design for the natural swimmers investigated.

Drag Model

At the Reynolds numbers of interest, fluid flow past an axisymmetric, streamlined body involves the following physics. The flow accelerates over the forebody from the stagnation point at the

nose. The boundary layer, initially laminar, increases in thickness until a region where laminar flow cannot be sustained. A transition region leads to fully developed turbulent flow and boundary layer growth. The skin friction, which is a large component of the drag, increases dramatically at the onset of turbulent flow. The turbulent boundary layer grows until separation from the body occurs or until the trailing edge is reached. Wake phenomena may disturb the boundary layer on the aft body. In addition, laminar separation may occur or turbulence may be induced by body defects or small discountinuities. The fluid drag on the body results from the cumulative effects of skin friction over the body and the net force in the aft direction due to the pressure distribution over the body.

Models for the laminar boundary layer and mainstream flow fluids are well established. There is less confidence in methods to predict transition, turbulent boundary layers, and separation due to an incomplete understanding of the physics of the basic phenomena. Even so, reasonably good methods for turbulent boundary layer flow correlated with empirical data have appeared in the literature. The models used were due to Smith, Cebeci and their co-workers [9], [10], [11]. Computer programs were available utilizing their models. It was established early in the research, however, that the optimization development would be independent of any particular drag model. As improvements in drag prediction appear, the models for the computation can easily be incorporated into the optimization program.

Because of the lack of generality of the available computation routines for boundary layer flow, severe but physically reasonable constraints were placed on the flow resulting from any body shape. For example, a lower limit was placed on the minimum pressure ratio. Also, a limit was placed on the maximum velocity ratio. Both of these restrictions were imposed to limit the possibility of separation, which is not allowed. When laminar separation occurs in a drag computation, turbulent reattachment is assumed. Separation before the trailing edge produces divergence in the drag computation. The determination of the point of transition from laminar to turbulent flow is the single most important drag model decision. The skin friction is almost negligibly low during laminar flow and rises abruptly with the onset of turbulent flow. Thus, low drag bodies rely on producing long runs of laminar flow. The possibility of exploiting laminar flow to reduce drag in submarine-like bodies was not considered a tractable option until tests in 1966 [1]. A body shape, dubbed the "Dolphin," designed to produce a long run of laminar boundary layer flow, produced significantly less drag than a similar

turbulent body. Previous tests [3] had indicated some drag reduction by shaping, but all the bodies tested were "turbulent" bodies. Since results are extant which have indicated that laminar flow exploitation may yield significant drag reduction, the model to predict transition becomes all important. For the present model, a criterion [12] is use correlating experimental data to produce a curve relating the running surface length Reynolds number to the momentum thickness Reynolds number. At the point where the curve produced by a particular body shape intersects this empirical curve, transition is predicted in the computation of the boundary layer. This criterion is, of course, subject to many criticisms but has demonstrated reasonable accuracy for body shapes such as the "Dolphin."

The drag computation itself uses Young's formula [11]. This result is preferred to integrating the local skin friction and pressure distribution to obtain the resultant force on the body due to the sensitivity of this latter computation to small errors in the data or the numerical procedure.

Optimization Formulation

The mathematical formulation leads to a problem in the classical calculus of variations with partial differential equations for the pressure coefficient and skin friction as constraints. The vehicle drag for the modeling procedure chosen depends only on the Reynolds number and the body shape.

If the problem were attacked by the calculus of variations, a set of necessary conditions which must be satisfied by the minimum drag shape would be obtained. The set of necessary conditions would be in the form of a two point boundary value problem which would have to be solved numerically and iteratively. In addition, any body shape thus found would be only a candidate for a minimum drag body since sufficiency conditions are not generally available. Since a numerical, iterative solution for the minimum drag shape was necessary and since this technique should apply independent of the particular computational technique for drag, the question was which iterative, numerical technique would be most efficient.

After extensive preliminary experience with the drag computation, it was decided to pursue a parametric optimization procedure using nonlinear programming techniques for constrained, optimization problems. There are presently available, even with a cursory count, some 30 different nonlinear programming techniques. Each has some

feature that makes it more or less tractable for a particular class of problems. One can draw several conclusions from the existence of such a large number of techniques. One obvious conclusion is that no universal method has arisen. Second, in all probability, a new optimization problem will require a new or modified method. Therefore, the choice of an appropriate optimization method was an important facet of the research. Initial experience indicated that a modification of the Complex [14] method would be an excellent candidate for the optimization. Subsequent research has verified that the method as modified by Guin and with a modified starting procedure is indeed a good one for initiating the minimization but that another technique must be used when approaching the minimum. The method used for convergence near the minimum is due to Powell [13].

Characterization of the Body Shape

With the decision to use a parametric optimization technique, an appropriate technique must be found to characterize the body shape by a set of parameters. The most general set of parameters for a numerical technique would be the set of the radius of the body at each grid point along the axis of symmetry. However, the constraints on such a set of parameters would be prohibitively complex. In addition, the number of parameters would be overly great. Obviously, a set of polynomials was the prime candidate for characterizing functions. Granville [14] has proposed a set for streamlined bodies which seemed ideally suited for the study. This set had been specified with constraints which guaranteed sufficient continuity for hydrodynamically smooth flow. Such constraints mean that the optimization results lose a degree of generality that the classical variational calculus solution retains. The solution is constrained to lie within the region of the specified functions only. Solutions completely different in character than that expected from streamlined bodies are disallowed. However, such streamlined bodies are implicitly assumed in the present drag model used. So until a drag computational method is available which could utilize a more general body shape, parameterizing the body shape assuming smooth functions is not a restriction, providing a sufficient set of parameters is used. Two types of parameter descriptions are used. The first uses 5 parameters and the second uses 8 parameters. Examples of the parameters are the radius of curvature at the nose, maximum diameter and location, curvature at the maximum diameter, etc. The

optimization procedure must manipulate these parameters to search iteratively for a minimum drag body.

Optimization Results

In Figures 1, 2, 3, and 4 a sample design, dubbed "X-35," produced by the present method, is compared with the "Dolphin," an experimentally verified design with half the drag of a conventional torpedo.

For this particular optimization problem, the results indicate that low drag designs are found by the optimization program. There are questions of uniqueness, and convergence is a problem. Extensive runs indicate that a unique minimum exists but that additional hydrodynamic constraints may have to be imposed to generate bodies with stable laminar flow. However, experimental data are needed to test this conjecture. In the meantime, research is continuing on designing the "best" optimization strategy under a highly nonlinear drag model with stringent constraints on both the input parameters and the intermediate and final hydrodynamic parameters.

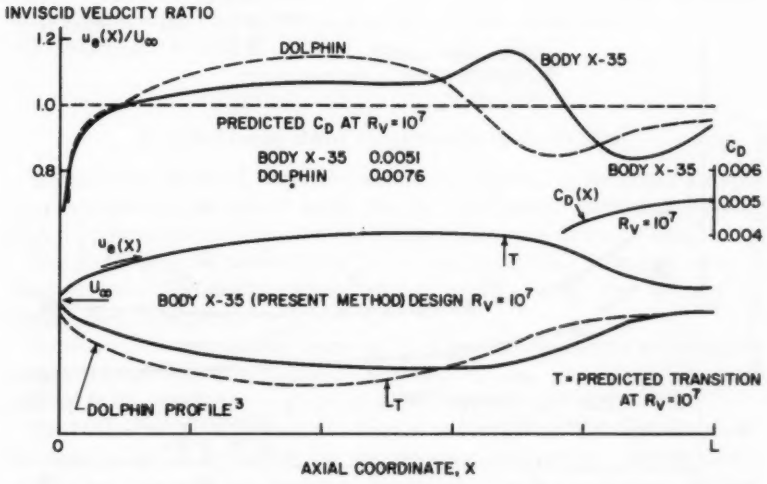

Figure 1. The design R_V(Reynolds number) of 10^7 for body X-35 corresponds to the Dolphin volume of 5.6 cubic feet at 40 knots in water. Body X-35 with its inviscid velocity distribution and C_D (drag coefficient) are shown here along with the Dolphin for comparison. The C_D for body X-35 is about one-third lower than that of the Dolphin at R_V of 10^7.

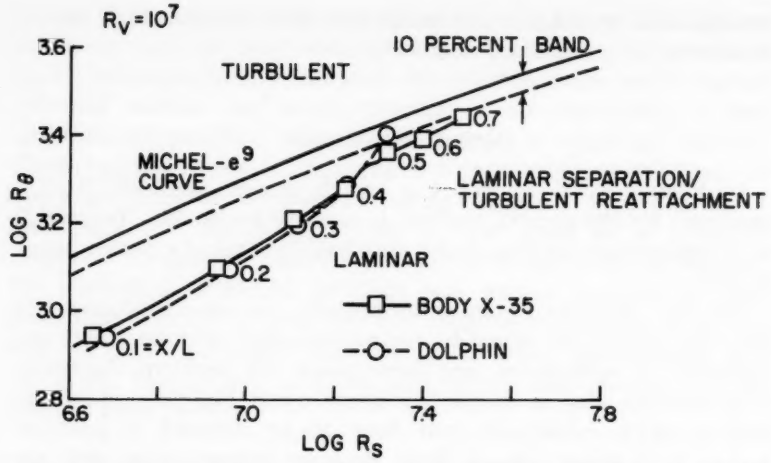

Figure 2. Transition predictions at R_V (Reynolds number of 10^7 for body X-35 and the Dolphin with the transition (Michel $-e^9$) curve.

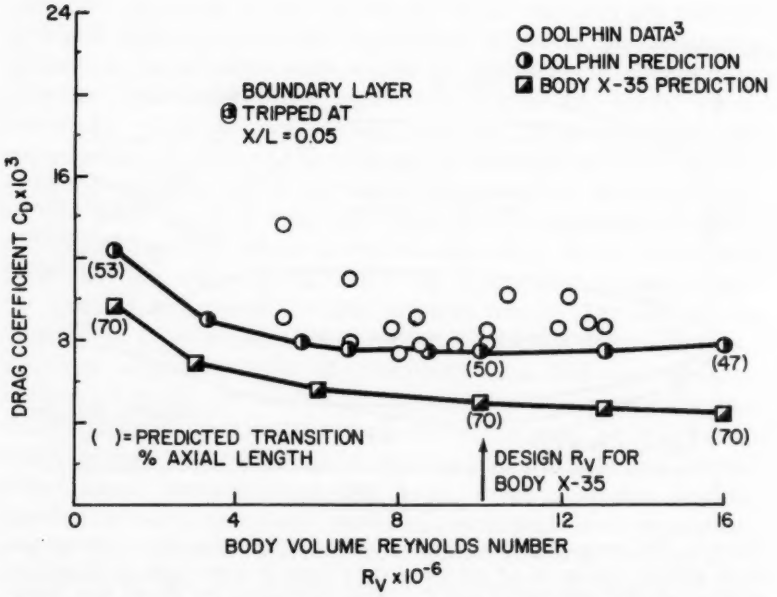

Figure 3. Predicted drag coefficients (C_D) for body X-35 and the Dolphin, as well as experimental data for the Dolphin over a range of Reynolds number.

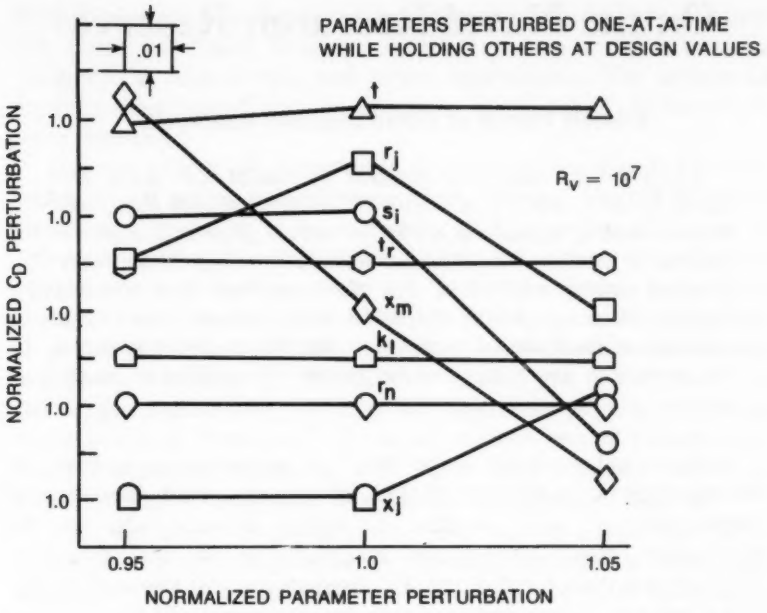

Figure 4. Perturbation studies on body X-35 at Reynolds number of 10^7. A plus and minus five percent perturbation is made on each dimensionless parameter while the other seven parameters are held at their design values.

A Sub-Towed Buoy Communications System

Scientists at the Naval Research Laboratory (NRL) have developed a towed buoy communications system under the Buoy Integrated Antenna Submarine (BIAS) program, sponsored by the Naval Ship Engineering Center.

The BIAS program was initiated to provide submerged submarines with a communications capability without unduly compromising their security or limiting their operations.

Because of the propagation losses suffered by electromagnetic waves during passage through the air-sea discontinuity and the sea, submarines have been required in the past to approach the surface to establish communications.

The NRL system is composed of a buoy, a towing device, and control circuits. The buoy serves as a platform for the antennas and contains radio-frequency transmitters, receivers, and associated control and interface equipment. A faired tow cable payed out or retrieved by a winch and drive assembly, tethers the buoy to a submerged submarine. Henry D. Cubbage, a member of NRL's Communication Sciences Division, is principal investigator for the system.

(Continued on page 24)

On the Naval Research Reserve

Possible Effects of Electromagnetic Radiations

The following report was prepared by RADM V.P. Bond, MC USNR-R and RADM E.P. Cronkite, MC USNR-R. RADM Bond, who holds a medical degree and a PhD in medical physics, is Associate Laboratory Director at Brookhaven National Laboratory. He is a Ready Reservist drilling with NRRC 3-9, Hamilton, New York and was recently selected for RADM. RADM Cronkite is a medical doctor and Chairman of the Medical Department at Brookhaven. He is renown for his research in hemotology and has written 350 publications on the subject.

Integral and essential to the Navy's communications systems are electromagnetic radiations (EMR) of a very wide spectrum of frequencies or wave lengths. Examples include radar in the microwave (approximately 200 megahertz to the low gigahertz) range, conventional radio and TV frequencies, (50 kilohertz to the low megahertz range), and extremely low frequency (ELF) radiations of the order of 40 to 70 Hertz, or cycles/second corresponding to wavelengths of many kilometers. These radiations do not produce ionizations in tissue. A large ELF generator for the principal purpose of communicating with submarines has been proposed by the Navy for the central region of the United States. Electric field densities at the surface of the earth over the antenna only approach 0.7 volts per meter. In addition, so extensive are the uses of EMR in military and civilian communications that ambient power densities in large installations or cities can be measured with little difficulty. A number of generators are frequently aboard a single ship, which of course increases the power densities. Because of possible deleterious biological effects of EMR, a primary exposure limit of 10 milliwatts/cm^2 has been established in the USA. The exposure limit recommended in the USSR is considerably less than this.

While on ACDUTRA in December 1973 and February 1974, the authors were asked to review the Navy's research programs designed to determine what, if any, effects on man may occur as a result of exposure to EMR. The Navy has several intramural investigative programs including those at the Naval Medical Research Institute at Bethesda; The School of Aerospace Medicine, Pensacola; the Naval Air Development Command, Warminster, Pennsylvania; the Naval Weapons Laboratory, Dahlgren, Virginia and the Armed Forces

Radiobiological Research Institute, Bethesda, Maryland. In addition, the Office of Naval Research supports a number of extramural programs at universities and other institutions. The intramural facilities were visited, and the programs of a number of laboratories were reviewed.

Definite effects of microwaves at higher power densities (of the order of 100 milliwatts/cm^2) have been observed. Most if not all of these are considered to be secondary to the heating of tissues. A principal finding is the development of rather characteristic opacifications of the lens of the eye. In addition, it has been found that some microorganisms will align themselves in an electrical field. It is also of interest that one can "hear" microwaves even at rather low power densities—the mechanism of this is not as yet known. At the longer wavelengths, there is no significant heating of tissues. Some so-called "athermal" effects of microwaves and radiations of lower frequencies, including ELF, have been reported. However, most if not all of these must be regarded as preliminary findings.

Although there are no generally held theories other than tissue heating at relatively high power levels to explain possible deleterious biological effects in mammals, more experiments must be done to rule out the unexpected. Thus over the next several years a series of concentrated and well controlled studies must be performed to determine whether there are in fact harmful biological effects of EMR, particularly at low power densities.

Project Dialogue Available

At a regular drill, Research Company 1-1 of Boston, Mass., welcomed CDR Paul J. Gerdon, USNR, its Research Reserve Sponsor, from ONR, Washington. CDR Gerdon's visit represents a growing effort to provide direct contact between ONR and members of the Research Reserve Program on a more personal basis, as well as to apprise members of current trends and policies in the reorganization of the Reserve Forces.

The company listened to a recorded presentation by the Chief of Naval Research, RADM M. D. VanOrden, USN. The taped commentary proved a unique method for furthering discussion of the present and future status of the Research Reserve. The consequences of establishing a mission-oriented reserve program, and the resulting demands placed upon each Research Company for providing its own innovative approaches to enhance this new trust was a major topic of the evening discussion.

CDR P. J. Gerdon, USNR, of ONR (Center) presents copy of Project Dialogue to LCDR A. G. Cameron, USNR, C. O. of USNR R Co. 1-1, Boston, for use by Co. 1-1 members. Other members of the Company Staff are (L to R) Ens. J. E. Cater, Capt C. F. Davis, and LCDR P. W. Chapman.

As illustrative of what has been accomplished in this vein, CDR Gerdon presented "Project Dialogue", a prepared film slide commentary which graphically portrays the development of the Office of Naval Research, and its various programs. Numerous projects in basic research are described with an emphasis upon the benefits of many of these programs to the civilian community. The educational and public relations aspects of this slide program are particularly good in view of the close liaison that exists between reserve forces and the non-military population. Project Dialogue is now available to all Research Reserve Companies; and all Research Reservists are being strongly encouraged to present it to local civilian groups. Those interested in obtaining Project Dialogue should contact the nearest Research Reserve Company. The September 1973 issue of *Naval Research Reviews* lists the 59 companies and their Commanding Officers throughout the United States.

Naval Hydrodynamics Symposium Hears Dr. Wiesner at MIT

The Tenth Naval Symposium on Hydrodynamics sponsored by the Office of Naval Research was held at the Massachusetts Institute of Technology, Cambridge, Massachusetts, during the week of June 24, 1974. This international symposium is held every other year to stimulate research in hydrodynamics by providing a forum for world leaders in this field to meet and discuss their latest ideas and discoveries.

Representatives from nine different countries in addition to the United States presented papers at the symposium. Virtually every maritime nation was represented through attendance at the symposium. Featured speakers at the opening session were Dr. Jerome Weisner, President of MIT, and Rear Admiral M.D. Van Orden, Chief of Naval Research.

In his address, Dr. Wiensер stated in part, "I take great pleasure in welcoming this, the 10th Biennial Symposium on Naval Hydrodynamics, here to MIT. I'm particularly pleased to be here because I feel a special bond to our sponsors, and particularly to the Office of Naval Research. Any American scientist who has the privilege of working under federal sponsorship, whether he knows it or not, owes a great deal to the Office of Naval Research. Following World War II, in a vacuum of research interests and support, the Office of Naval Research was set up under the inspired leadership of some people who had witnessed the contribution that science could make to naval warfare and naval matters during the war. They held wartime basic research activities together and established a very farsighted program under the Office of Naval Research that set the pattern which ultimately led to the National Science Foundation. Nonetheless, the Office of Naval Research has continued to be an important sponsor of basic and applied research in this country. It has provided an important link between scientists and engineers in American universities and our armed services. We have always found that ONR provided a degree of understanding present in very few other sponsoring agencies, probably because of the direct involvement of so many of the people in ONR in the ongoing activities of the Navy. When I was a working scientist-engineer, involved with military electronics, particularly radar, I always found it a special pleasure to work with the Navy, partially because of the severe technical demands that a seaborne environment placed on equipment, and partially because of the deep understanding I found among the people I had to work with. I always got a special pleasure out of being aboard ship. I used to suspect that I hadn't grown up, because all the gadgets and devices I found on submarines and ships gave me a thrill. Later in life, just a few years ago, I discovered in talking to Buckminster

Fuller that the Navy had been his inspiration that led to such things, he claimed, as the geodesic dome and a variety of other things. He put it very simple that, while most of us spend our engineering hours learning how to do more with more, in the shipborne environment you had to learn how to do more with less. This was the lesson that he had learned as a young Navy officer aboard a submarine, and it never left him."

Rear Admiral Van Orden in his remarks pointed out that the Symposium on Naval Hydrodynamics is one of several international symposia held by ONR "that helps to fulfill a principal ONR objective, which is to conduct a continual survey of world-wide findings, trends, potentialities and achievements in research and development of interest to the Navy."

He also made the following points in his talk: "For the Navy, progress in hydrodynamics research has become increasingly urgent. Traditionally our goal has been to design new and improved types of ships that not only make use of advanced technology but also operate efficiently, reliably and safely. Now we face a new challenge in the construction of ships to sail on or beneath the unforgiving sea.

"Today our nation is faced with the dilemma that we must make do with a much smaller Navy but still retain our global responsibility. This means we must plan types of ships that are radically different in design from anything in the past in order to meet this requirement. At the same time, these ships must be inexpensive to operate and maintain in addition to satisfying our traditional standards.

"The results of the research that will be reported at this symposium should help us move toward that formidable goal. It is clear that all of you here today are dedicated scientists, so I do not need to urge you to keep pressing forward in your search for solutions to the frustrating problems in hydrodynamics. I would like to stress, however, that you maintain strong lines of communication so that as many people as possible can benefit when you inevitably succeed in your endeavors."

The complete proceedings of the symposium will be published at a later date.

(Continued from page 19)

The entire buoy-deployment subsystem is controlled by logic circuitry and can operate automatically. Various control panels and power supplies make up the remainder of the system.

In normal operation, the buoy is payed out from the submarine and allowed to rise close enough to the surface to establish communications.

After successful laboratory test, the system was installed on an operating submarine where the system is undergoing further evaluation.

Research Notes

Project SHAD II Completed

On 12 April of this year the divers of Project SHAD II ended a prolonged confinement by returning to normal atmospheric pressure after a record-breaking twenty-nine day compressed air saturation dive at a simulated depth of sixty-feet of sea water.

The Navy's second shallow-habital, air dive (Project SHAD II) began on 15 March when the hyperbaric chamber at the Naval Submarine Medical Research Laboratory, Groton, Connecticut, was sealed with two volunteer Navy divers inside as subjects. The chamber, which simulates an intra-ocean habitat, was pressurized to an environmental pressure of 60 feet of sea water. The divers made several simulated excursions in their habitat to depths as deep as 250 feet of sea water and as shallow as 5 feet of sea water.

Captain Vernon A. Burkhart, MC, USN, Commanding Officer, Naval Medical Center, congratulates the first diver to emerge from SHAD II, Torpedoman Second Class (DV) Gary Seibert, USN.

This experimental "dive" is part of the SHAD series which began in October 1973 with a highly successful 30-day exposure of two men at a simulated depth of fifty feet of sea water, while breathing compressed air rather than the very exotic gas mixtures which have been used in most saturation dives.

The SHAD program is designed to explore the feasibility of utilizing compressed air for saturation diving in the open ocean at moderate depths. Heretofore, the uncertainty of the biomedical effects of the high partial pressure of oxygen in compressed air environments has limited the practical use of compressed air in saturation diving. At present, marine biologists, marine geologists, oceanographers, and salvage divers must rely upon expensive specialized gas mixtures for their undersea endeavors. The ready availability and low cost of compressed air as a breathing medium should greatly facilitate man's quest to understand the myriad mysteries of the undersea world and his drive to discover and harness the rich resorces hidden in the new frontiers of the continental shelf. The matter of undersea salvage is of direct interest to the Navy.

The two United States Navy divers in SHAD II were selected from a field of experienced volunteer divers during a rigorous pre-dive training and selection program: Hull Technician Chief (DV) Raymond Fine, who is one of the divers credited with the United States Navy's deepest recorded open-water dive of 1,010 feet, and Torpedoman second class (DV) Gary Seibert.

LCDR George M. Adams, MSC, USN, a diving physiologist, and head of the Diving Research Branch of NavSubMedRschLab, is the Principal Investigator and Project Coordinator for the SHAD program. Together with LT Roger A. Williamson, MC, USNR, coordinator of the medical supervisory team, and Chief Engineman James Jordan, (DVM), USN (Ret), diving supervisor, he has supervised the collection of data for wide spectrum of biomedical functions.

The dive has been the longest recorded compressed air dive at 60 feet in this country. Bother divers emerged in good health and spirits.

Navy Test Satellite to be Fired into Orbit by Air Force

A Naval Research Laboratory (NRL) experimental satellite will be fired into orbit soon from the Western Test Range by an Air Force Atlas F Missile as a test vehicle for the forthcoming Department of Defense worldwide navigational system now under development.

The pilot satellite, designed, built and fabricated at NRL will be put into a near-7,500 nautical mile, 125-degree inclined orbit.

The NTS-1/TIMATION III (Navigational Technology Satellite and TIMATION for TIMe navigATION), is a forerunner of the proposed NAVSTAR Global Positioning System to be developed as a team effort by the Army, Air Force and Navy.

The USAF has been named as the executive service in the development of the NAVSTAR Global Positioning System, while the Naval Research Laboratory will furnish the scientific data for the development of the system based on experience gained from the success of this and previous TIMATION efforts.

Equipment aboard NTS-1/TIMATION III will be used to determine the accuracy that can be achieved by using crystal oscillators and rubidium atomic clocks for an advanced system to provide precise time transfer, navigation, and geodesy.

The doughnut-shaped satellite, weighing some 2300 pounds before flight and about 650 pounds after its two solid-fueled engines are released, will transmit signals in the 335 mc and L band regions to obtain a direct measurement of ionospheric effects on satellite ranging.

The TIMATION technique, used as the concept for the new system, has been proven an ideal method to enable ships and aircraft to obtain highly accurate fixes of their positions in any type of weather.

The technique is passive, requiring no signal transmission by users such as ships or aircraft, and is considered more easily used and more accurate than conventional navigational/time systems.

The NAVSTAR Global Positioning System would employ a number of satellites to enable a pilot or navigator to make direct simultaneous measurements of ultra-high-frequency signals emitted by precision oscillators in two or more of the satellites.

In such a system, the signal transmission-to-receipt time can be converted into distance measurements, and position can be determined by applying standard navigation techniques. The same highly accurate information can be obtained by direct measurement of two signals from a single a satellite. With either approach, no elapsed time is required for a navigation fix.

In the new global operational system, signals will be received automatically from the satellites and converted to highly precise position elements. This will allow the user to read his position and altitude very accurately at all times.

Scientists Resolve Ordnance Problem

Naval Research Laboratory (NRL) scientists have developed a system to determine the presence of small, half-inch-long aluminum wire shear pins, used in primers of large naval shells.

Officials at the Naval Ordnance Station (NOS), Indian Head, Md. were aware that the absence of this wire shear pin in the Ex 161 primer could result in accidental detonation of the primer and the shell, with obviously serious consequences.

Many techniques had been tried by NOS, including manual inspection, in an attempt to ensure that the small shear pin was actually in position in each shell after assembly. However, the small fraction of shells still "passing" inspection without pins was dangerously high. NRL scientists were then consulted in hopes of developing a more reliable technique of inspection to prove unerringly after assembly that each pin was indeed properly inserted.

The NRL scientists suggested that by use of a little known nuclear reaction produced by high energy x-rays from the NRL Linear Accelerator (LINAC), the aluminum pins could be made radioactive. This particular radioactivity displays the unusual property of emitting two gamma rays simultaneously. This enables the inspection equipment to differentiate this radiation from normal background radiation from cosmic rays and from other materials.

Dr. Kenneth M. Murray, the principal investigator in the project, reported that the radioactivity in the pin is of such a low level that it is considered negligible according to AEC standards and will not present any danger to personnel even if they handled a large number of pins. Even though the radioactivity becomes weaker with time, the pins will be readily detectable by the NRL-Built equipment for 10 years or more.

Furthermore, says Dr. Murray, the price of producing the radioactive shear pins for the navy would be reasonable. He said that the LINAC costs $130.00 per hour to operate and that it would take about one-and-a-half man days to process about 10,000 of the pins. To produce enough activity to achieve a 10-year useful life for the pins would require about 30 hours of LINAC beam time.

The system has been demonstrated to be capable of meeting or exceeding all the requirements initially placed on it. It is presently being evaluated in a pilot production line at NOS, operated and attended by NOS personnel. The problems of incorporating it into a routine production line operation are now being studied.

Concrete for Deep Sea Construction

Daily, for the past 30 months, the ocean near the Channel Islands off the Southern California coast has been playing a continuous role in determining the future of concrete as a potential material for deep sea construction.

In September, 1971, the Civil Engineering Laboratory (CEL), Port Hueneme, Calif. placed 18 concrete spheres into the deep ocean. Some of the structures are not scheduled for recovery until 1981. Deployment depths range from 2,000 to 5,000 feet and marked the first time such a large scale test had been programmed over a prolonged period of time.

Each sphere weighs more than 4,000 pounds, has an outside diameter of 66 inches and has walls four inches thick.

Although CEL is only 2 1/2 years into the 10-year program, partial data have been most revealing and encouraging. Harvey H. Haynes, senior research structural engineer in charge of the project, said in situ inspections reveal (1) less water within the structures than originally predicted and (2) the rate of seawater permeability decreases with time.

No one has previously conducted ocean tests of this magnitude on concrete structures. Up to now, engineers have had to rely on pressure chamber data and results from shorter tests.

The average water seepage into the emplaced structures was about six gallons per sphere coated with epoxy and 12 gallons per uncoated sphere. Eight spheres were waterproofed with an epoxy plastic and eight were not treated. Pressure chamber tests had indicated twice this permeability for the spheres.

Each structure was rigged with heavy chain which acts as an anchor and a permeability indicator. The spheres, when emplaced in 1971, were secured 32 feet off the seafloor. As the structure takes on water it gets heavier and forces

the chain to settle slowly to the ocean bottom. Thus the number of links remaining upright are easily counted during periodic inspections. Haynes said that one collapsed link represents about 3 1/2 gallons of water permeated into the sphere.

Results also show that the longer the concrete remains exposed to deep ocean pressures, the less amount of water passes through the four-inch walls.

As expected in this project, all spheres have not escaped failure. Of the 15 inspected within the first 30 months, two had imploded and a third had developed a slow leak and had sunk to the seafloor. One implosion apparently occurred during emplacement at 4,330 feet, judging from pieces of concrete scattered on the seafloor. The other failed within the first year at the 3,725-foot level. This sphere did not contain a clock mechanism that was placed in several other deep structures. The device records the number of days a sphere has been in the deep ocean. Upon implosion the clock stops, providing engineers with an accurate time reference.

Haynes said that water trickling through an epoxy-concrete joint had caused the other sphere to settle slowly to the bottom. He surmised that the problem area was the equatorial joint which bonds together two hemisphere sections making up the sphere.

Four inspection dives have been made, the latest being this winter. The Laboratory has used Scripps Institution of Oceanography's unmanned Remote Underwater Manipulator (RUM) and two three-man submersibles, Turtle and Seacliff, owned and operated by the Navy's Submarine Development Group 1, San Diego.

The three remaining spheres not yet inspected will be visted this summer by the unmanned Curv III vehicle.

The seven deepest spheres are expected to fail eventually because ocean pressures at those depths approach the long term failure pressures of the spheres. The sustained loads will cause them to implode under static fatigue.

CEL is the only laboratory conducting research of pressure-resistant concrete structures for deep ocean construction. The Laboratory considers the material ideal for the sea since it is inexpensive, corrosion resistant, reacts well to compression, and can be fabricated at thicknesses which provide buoyancy control.

Some engineers believe that within 15 years large concrete habitats with diameters up to 100 feet will be built on the ocean bottom.

Can You See With Sound?

This concept of seeing with sound represents part of the nondestructive testing (NDT) expertise being generated at Naval Weapons Laboratory (NWL) for application to some of the Navy's NDT inspection needs. Principal investigators involved with this work are Dr. Gerry Blessing, Dr. Steve Fishman, and Mr. Jeff Warren of NWL and Dr. Paul St. Hilaire of Georgetown University.

There are many instances of Naval inspection needs for objects that are opaque to light but transparent to sound energy at very high (ultrasonic) sound frequencies. At these sound frequencies the presence of flaws can be detected by passing sound through the object. Examples of such inspection needs include cracks in gun barrels and projectile bodies, voids in cast explosives, and many aspects of quality control such as thickness measurements.

The principal investigation currently in progress is an effort to obtain an assembly line technique for the complete ultrasonic inspection of the cast explosive billet to be used in the HIFRAG two-piece projectile (5"/54). The innovative design of this projectile allows for a 100 percent inspection capability of the billets which are precast into plastic beakers, prior to their being loaded into the projectile body shell. Compared with the traditional one-piece projectile, this design provides two principal inspection advantages in addition to a greater ease of handling: safety and improved reliability of inspection results. Inspection of the billet prior to loading reduces the danger of handling a loaded round, and greatly facilitates minimum flaw size detectability.

It is the goal of this program to provided an inspection system that will detect the presence of air bubbles or voids that form in the billet during the casting process. Evidence exists that voids on the order of, or greater than 0.1 inches in diameter may lead to a premature burning of the explosive in the gun barrel when the projectile is fired.

Advantages accrued from an ultrasonic system as opposed to the traditional dry film X-ray inspection process include real-time detection, lower costs, safety (no radiation hazard present), and most importantly the minimization of error that is inevitable when human judgment is required. Automated alarm circuitry may be used with the proposed inspection process so that an operator would be alerted to the presence of a flaw by a ringing alarm and/or flashing light.

To optimize the performance of an inspection system for detecting minimum size flaws, the following steps are taken: (1) design, (2) building, and (3) testing. An initial design concept prescribes a particular configuration of acoustic transducers which act to both generate (transmit) and detect the sound energy. This process requires a liquid medium to couple the sound energy to the object under inspection, and in our case the encapsulated billet is submerged in a water tank for the test. A focusing lens is attached to each transducer so that, in a fashion similar to focusing a light source, one may obtain a comparatively narrow region of sound energy for purposes of increased flaw detectability.

The appropriate transducers are then built and the sound profile of the transmitter is visually observed by shining light on the wave pattern as it moves through the water.

NUC Polymer Research May Aid Firefighters

Water, obviously, has many uses: drinking, cooking, washing.

Under pressure, water can be used to fight fires, to clean high voltage line insulators, and even to cut paper, wood and metal. Pressure alone, however,

is not sufficient for cutting purposes, and its effectiveness in fire fighting could be improved.

The problem is that, as the water jet travels away from the nozzle, air friction causes it to break up, scattering into droplets and flaring out to form a cone-shaped spray. One method that has proven successful in reducing water jet dispersion is the introduction of a polymer into the water. Engineers at the Naval Undersea Center (NUC) have been involved in research on the drag-reduction capabilities of polymers for 15 years.

During tests aimed at reducing turbulent friction of water in fire hoses, the researchers discovered that the polymer solution also reduced water jet dispersion. A study into the discovery, funded by the Office of Naval Research, was undertaken by Dr. J.W. Hoyt, Associate for Science of Fleet Engineering Department.

Unexpected assistance in the effort came from J.J. Taylor, a former employee of Western Electric Company.

Curious to know why workmen using pressure hoses to clean highvoltage insulators were not electrocuted by feedback, Taylor invented a camera in his home workshop to study water jets. He found that the water jet tended to break up as it moved away from the nozzle, and since there was no continuity in the water stream, the electrical current had no conductor back to the man on the hose.

The high quality of the photographs Taylor obtained led Dr. Hoyt to propose use of the camera to study water jet dispersion. The photos showed excellent detail, providing the researchers with previously unattainable information on jet spray break-up.

The image-motion compensating camera is equipped with highspeed rubber rollers which drive a 2-1/4 X 3-1/4 inch piece of cut film past the lens and behind it at a velocity matching that of the water jet.

When the film is in the center of the lens, an electronic strobe is flashed for a short duration (15 microseconds). Illuminating the jet from behind, the flash is used in conjunction with a translucent plastic diffuser to avoid "washing out" the film negative.

Exposures of f-22 using Kodak Tri-X Pan rated at ASA 320 were made, providing good negative detail. The polymer used for the studies was poly (ethylene oxide), a common industrial chemical.

The detailed photographs show the jet structure is made up of an initially laminar flow. (The smooth, even flow characteristic of water moving slowly through a pipe, for example, is laminar.)

A series of eruptions then occurs on the surface of the jet, and spray droplets begin breaking off as an oscillating wave region is formed. Introduction of the polymer at concentrations of 10 parts per million (ppm) causes "substantial reduction" in formation of spray droplets.

At concentrations of 50 ppm and above, spray formation ceases. Increased transparency and smoothness of the water jet's external surface accompanies the reduction of spray formation.

The effect of the polymer is thus to reduce, dampen or eliminate the small-scale distrubances while not reducing and in some cases even amplifying the

larger scale motions. This was reported in a paper published in the May 15 issue of the *Journal of Fluid Mechanics*.

The most striking effect of polymer addition was demonstrated at the 200 ppm concentration, where break-up of the water jet is accompanied by formation of filaments which link together all drops. (Figure 1)

Dr. Hoyt said the study represented a new approach to NUC's research into the basic mechanism behind the effects of polymer addition to fluids, and provided a different way of visualizing and studying polymers. The idea that the

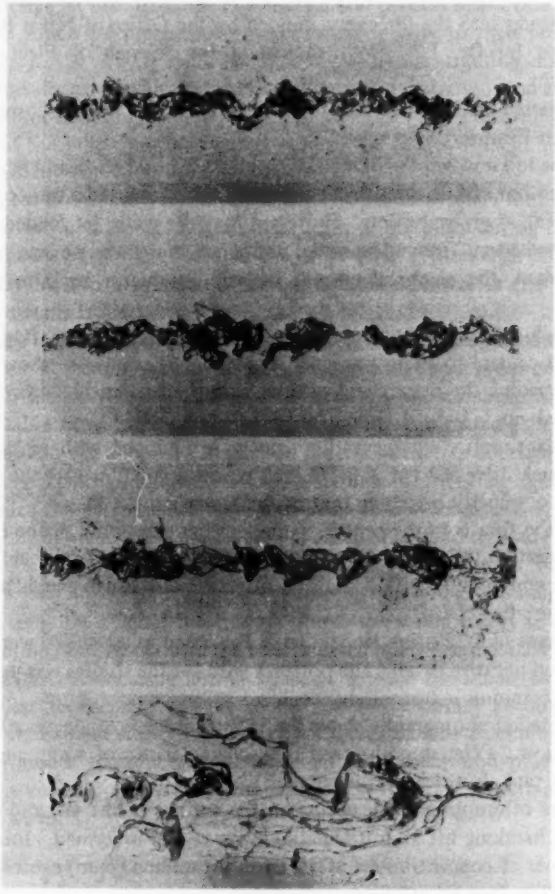

Figure 1 — Six feet away—These photos show the same water jets six feet from the nozzle. They show, again concentrations of (top-bottom) 0, 10, 50 and 200 parts per million of polymer. Note the string-like polymer substances holding water droplets together in bottom photo.

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water jets are more coherent with polymer addition was certainly not predictable from previous work, at NUC.

Research will be done at NUC next year to study fire hose nozzles in an attempt to maximize effectiveness in fighting fires.

These efforts are the second major civilian use spin-off of NUC's polymer research. Dr. Hoyt was issued a patent in 1972 for his work in the use of polymer solutions to reduce turbulent blood flow during transfusions, and thus reduce the work required of the heart at a traumatic time.

Other medical applications suggested by Hoyt and his associates include use of polymer solutions to reduce turbulent blood flow and thus temporarily lower blood pressure for those suffering from atherosclerosis, a disease characterized by fattly deposits which constrict the blood vessels.

This blockage causes turbulent blood flow in the area, and the heart is forced to pump harder, increasing blood pressure. Introduction of polymer solutions can give the heart a temporary rest.

Dr. Hoyt's pioneering work in polymer research earned him one of the first two Freeman Scholarships of the American Society of Mechanical Engineers in 1971, for which he wrote a comprehensive report on polymer utilization.

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Cover Caption

Artist's concept of TIMATION III Satellite as it looks "on station," orbiting at an altitude of 7,500 nautical miles above the earth. The extendable gravity gradient booms, above and below the satellite, will keep the antennas pointed to the earth at all times. *See page 26.*

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